

High Performance Regenerative Receiver Design

There have been several popular Regen projects in recent QSTs and ARRL Handbooks. Look at the design process and progress; then build one—or both—of the receivers described.

By Charles Kitchin, N1TEV

Many hams have tried regenerative receivers with mixed results. Some people are quite attached to "regens," while others consider them only suitable for beginner experimentation.

I have spent several years researching this subject and have come away with a great respect for the technical knowledge possessed by the "old-timers" of the 1920s and '30s. Unfortunately, much of this knowledge has been forgotten. Many significant discoveries, such as the "throttle"-capacitor regeneration control are unknown to most modern homebrewers.

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This article will show that, if properly designed, a modern regen is quite capable of direct-conversion or superheterodyne-level performance, although it does require greater operator skill. Attention to a few simple details can provide an excellent receiver for ham or general-coverage shortwave use. For beginners and veterans alike, studying, building and using regenerative circuits can add new interest, excitement and fun to the radio hobby.

A Brief History

The regenerative circuit was used in both commercial and ham receivers in the 1920s until the early 1930s. It was the standard ham receiver during this period, and a great deal of experimental work was done to optimize its performance. As the great depression slowly ended, the use of the regen de-

clined, because many people could then afford to buy commercial superheterodyne receivers.

Hams continued to use regens, usually homebrewed, through the rest of the 1930s. Although better components were then available, regens of the 1940s and '50s had been reduced to introductory sets for beginners—with generally poor performance.

By the 1960s and '70s, regenerative circuits had been replaced by the now popular direct-conversion receiver.

Regeneration Basics: What's Really Happening Here?

Fig 1 shows the basic regenerative circuit, discovered by Edwin Howard Armstrong¹ in 1914.

Fig 2 shows a modern equivalent

¹Notes appear on page 36.

circuit. Positive feedback, termed "regeneration" can be used to dramatically increase both the sensitivity and selectivity of RF circuits. Although a regenerative circuit may look very simple, how it actually functions is not simple. Its operation is both complex and quite fascinating.

If the output of an RF amplifier is fed back to its input—in phase—any signal present within this loop will be repetitively reamplified, typically providing a thousand-fold increase in gain over the same stage without regeneration. Although the power gain of a tube or transistor is fixed, the voltage gain in a regenerative circuit (ideally) approaches infinity at the point of oscillation. In actual use, infinite gain is not possible, due to phase shifts within the feedback loop. The practical result, however, is that a modern regenerative detector using a single transistor or JFET can achieve circuit gains of 20,000 or more.

Regeneration introduces a negative resistance into a circuit such that its net positive resistance is reduced. Since the circuit's selectivity, or Q , is equal to its reactance divided by its overall resistance, selectivity is also greatly increased when regeneration is applied.

When set below self-oscillation, regeneration provides a stable increase in both gain and selectivity. With more regeneration, the circuit reaches a very critical state, just at the threshold of oscillation. The exact "balancing" point—where the net circuit resistance is zero—is impossible to main-

tain, as even the smallest random noise source, given time, will build up to a self-sustained free oscillation.

With more regeneration, the circuit exhibits a net negative resistance and oscillates. As regeneration is increased further, curious secondary oscillations of a lower frequency are often created. These break up the main oscillation into a series of groups that periodically turn off or "quench" the main oscillation. Because of the quenching action, RF input signals build up to very high levels repeatedly, providing circuit gains approaching one million in a single stage. Discovered by Armstrong,² this phenomena is termed "Super Regeneration," and its development by radio amateurs led to the first practical VHF receivers.^{3,4}

Common Receiver Architectures: A Quick Overview

Fig 3 shows the block diagrams of regenerative, direct-conversion and superheterodyne receiver circuits. Let's take a look at their strengths and weaknesses.

Regenerative Circuit

As shown in Fig 3A, a regen uses an oscillating detector to heterodyne with an incoming RF signal at nearly the same frequency. The detector provides an audio output and, at the same time, functions as a very-high-gain RF amplifier and Q multiplier. So, a regenerative circuit oscillates, heterodynes, multiplies Q and amplifies simultaneously within a single stage.

By the use of positive feedback, a

regenerative detector typically provides an audio output level of hundreds of millivolts. Because of its inherent high selectivity, high Q band-pass filtering ahead of the detector is not needed; this greatly simplifies the design. Another interesting characteristic of regenerative detectors is their ability to detect nearly all types of signals, including AM, CW, single-sideband (SSB) and FM signals. Because regenerative circuits generally use fewer components, they tend to consume less power, cost less and are easier to homebrew than other receivers. Although parts reduction is always important, many regens have been built without much regard to their operating performance. Often, the addition of just a few more components and attention to a few important details will greatly improve receiver performance.

A regen can provide very high quality audio. A regen allows you full control of the circuit's selectivity, which is often desirable. In fact, this user-controlled selectivity feature allows decent-quality reception of FM signals. A regen's variable selectivity allows the operator to optimize the slope of the receiver's amplitude versus frequency characteristic. The fixed, high selectivity of most superhet receivers prevents them from effectively demodulating FM signals by slope detection.

In use, a regenerative circuit performs quite differently depending on whether it is operated above or below the oscillation threshold. When receiv-

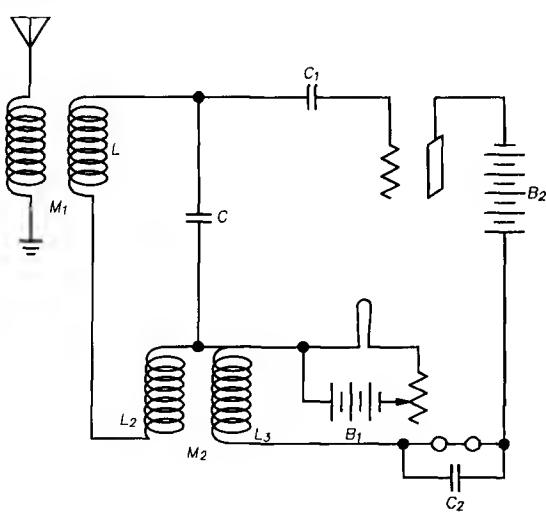


Fig 1—Armstrong's original regenerative circuit.

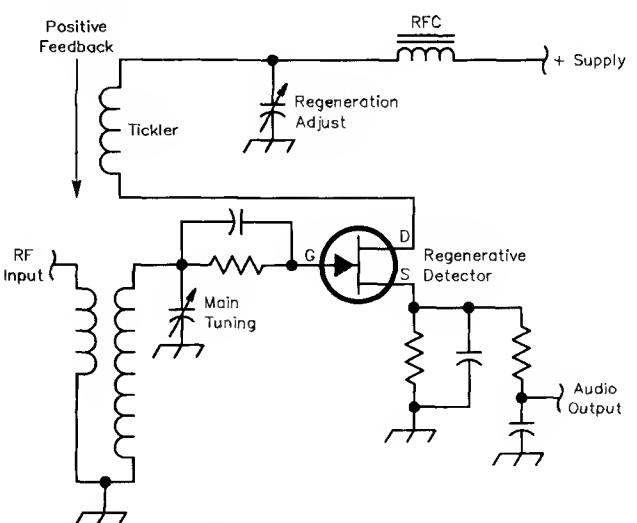


Fig 2—A modern regenerative detector circuit.

ing AM signals, the detector is adjusted just to the threshold of oscillation for the best sensitivity and selectivity. Receiver performance can be quite good but it does require frequent readjustment of the regeneration control and a certain amount of operator skill.

When receiving CW or SSB, however, the detector is set to oscillate and the receiver is tuned away from the center of the carrier to produce an audio heterodyne (beat note). An oscillating detector is far more sensitive than any other. In addition, the grid-leak biasing normally used with these circuits tends to maintain a nearly constant oscillation amplitude over wide frequency ranges and, therefore, requires very little readjustment.

Regen negatives include potential detector RF leakage out the antenna, requiring some type of isolation: typically an RF stage.⁵ Another inherent problem is "blocking," where an oscillating detector tends to lock to the

center of strong RF signals. The cure for this is some kind of variable input attenuation. When using a regen next to a transmitter, the high transmit RF levels produce severe blocking, which prevents using the regen as a keying monitor. The solution is a sidetone circuit, Piezo buzzer or similar device added to the transmitter circuitry. A final problem is hum modulation at the higher HF frequencies, those above approximately 14 MHz. When used in the oscillating mode, the RF output from the detector finds its way back to the antenna where it heterodynes with incoming RF signals. The solution is an RF stage with good isolation.

The audio quality (low distortion, wide bandwidth, low noise) of my homebrew regens in the AM mode is very noticeable and much better than any superhet I have used. I suspect that part of the reason for this is that the normal half-wave diode detector used in most superhets can generate

very high levels of harmonic distortion. This, combined with distortion in the mixer stage, can produce harmonic-distortion levels of 20% or more. Diode-detector circuits are fine for FM reception as AM harmonic distortion products are removed by the limiter and discriminator stages.

Direct-Conversion

As shown by Fig 3B, the heterodyne or direct-conversion (D-C) receiver has many similarities to a regen operating in the oscillating mode. Both mix a local oscillator signal with the incoming RF to produce a frequency output in the audio range. Because a D-C receiver's RF selectivity is determined in the front end, the reception range is usually limited to just a single ham band, with the RF input fixed-tuned to the center of that band.

The key difference between the two architectures is that in the regenerative circuit, both the circuit's gain and

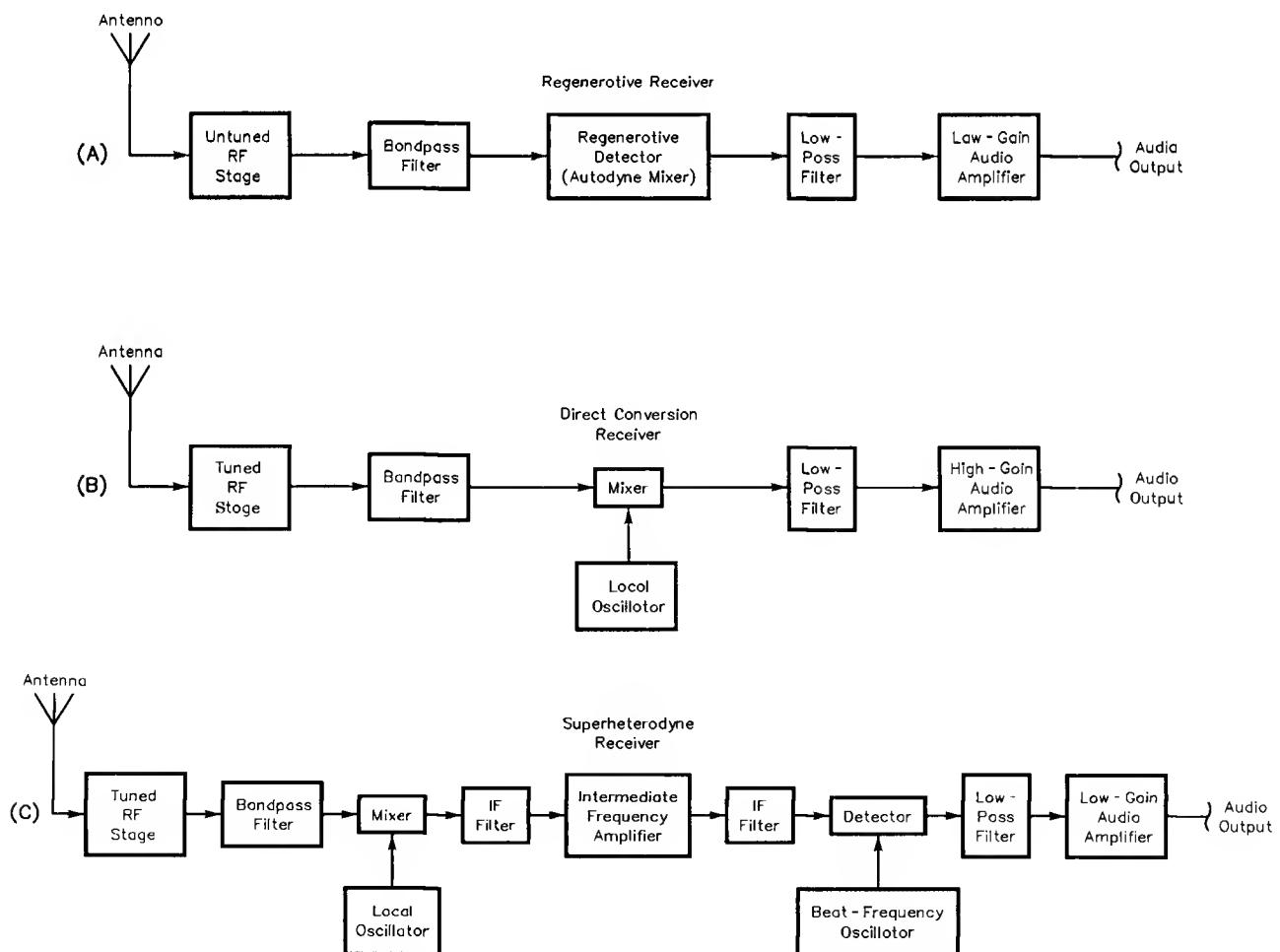


Fig 3—Some common receiver architectures.

selectivity are amplified a thousand times or more during the heterodyne process. This means that the regen has much greater RF selectivity and gain. At the same time, both the gain and selectivity of the regen circuit can drop dramatically with very strong input signals. To achieve the same gain and selectivity, a D-C receiver needs RF gain and preselection before the mixer plus a very high gain, very selective audio section. However, the D-C receiver is easier to operate than the regen.

A good analogy here are two cars, one with an automatic transmission (D-C receiver) and one with a manual or "stick shift" (regen). The regen needs good design and several controls (plus operator skill) to perform, but is capable of very high sensitivity and selectivity.

As with the regen, the D-C receiver's oscillator can leak to the antenna. It requires an RF stage or mixer with very high LO isolation. The very low AF input level can make the D-C receiver prone to microphonics. Modern D-C homebrewers have developed many clever designs to overcome these difficulties, but the low-cost commercial D-C rigs I have tried suffer from very poor selectivity. This reinforces my belief that it is not receiver configuration, but rather the design, construction and operating skills of the builder that really matter.

Superhet

The superhet receiver (Fig 3C) mixes the RF signal and that of an LO to produce an IF signal. The LO tracks the received frequency such that the sum or difference between the two frequencies always equals the IF. In a superhet, most of the amplification is provided at the IF using a high-gain, high-Q, single-frequency amplifier. When a single IF is used, it is usually lower than the received frequency because LC circuits of constant Q provide better selectivity at lower frequencies. For example, a 10 MHz LC circuit with a Q of 100 provides a bandwidth (selectivity) of approximately 100 kHz ($10,000,000 \div 100 = 100,000$), but at 455 kHz its selectivity is 4.55 kHz ($455,000 \div 100 = 4550$).

So, a superhet mixes the signal frequency to a fixed IF rather than use multiple high-Q RF amplifiers to cover the entire frequency range of the receiver. Oscillator leakage is minimal in superhets because the LO usually operates far from the received frequency. Thus, the oscillator's leakage

is greatly attenuated by the receiver's input circuitry.

On the negative side, superhets are difficult to homebrew unless the range of received frequencies is very small. Although the IF filter(s) eliminates the need for single-signal front-end selectivity, it's still important that the front end eliminate the IF image frequency from the passband. (Images occur because the LO can heterodyne with frequencies both above and below the IF.) This is easily accomplished for single-band receivers by choosing a fortuitous IF. For a single band, several low-cost crystals (for IF selectivity) together with a fairly high IF can provide a decent receiver.

Nevertheless, to homebrew a good multiband superhet, you need to either bandswitch among selective front ends or use multiple conversions and up-convert to a first IF well above the highest received frequency. (For example, a 75 MHz IF for a 0.3 to 30 MHz receiver.) While some kits take the first option, these requirements have made the superhet impractical for all but the most skilled homebrewer.

Regeneration Control Methods

Figs 4A to 4E, from the *1931 ARRL Handbook*,⁶ show several types of regeneration control methods then used. The rotating or "movable tickler" method (4A) often used a variometer to adjust the amount of positive feedback. This method is prone to very severe detuning of the input signal as the regeneration level is increased.

Figs 4D and 4E show resistive control methods. A potentiometer or rheostat controls the detector's operating voltage. As the detector's plate or filament supply voltage is raised, its gain increases, causing an increase in regeneration.

The major problem with this method is that it suffers from a hysteresis effect when you adjust the control: It overshoots and requires readjustment. It's very difficult to set the regeneration level right at the oscillation threshold, a requirement for high selectivity in AM reception. When receiving CW, there is often a serious drift in the beat note with changes in signal level, temperature or power supply.

When screen-grid vacuum tubes came into common use, a resistive regeneration control that varied the screen voltage of the detector was common. Fig 4F shows a typical circuit from the *1942 Handbook*.⁷ Stability was better in this "electron-coupled"

oscillator circuit (as the screen was electrically isolated from the plate) but since the detector voltage was not regulated, it still varied, changing the regeneration level.

Figs 4B and 4C show the throttle-capacitor method. From a performance standpoint, this is far better than any resistive control. A well-made capacitive throttle allows regeneration to be set "right on the edge" of oscillation, resulting in great selectivity and sensitivity. With a capacitive control, the detector's supply voltage can be regulated, using a Zener diode or other means. In actual operation, this method provides a very dramatic improvement in regenerative-detector stability.

An RF Stage Preceding the Detector?

Back when many ham receivers used vacuum-tube regenerative detectors, power levels were high, often causing interference to other receivers in the area. As an example, a tube detector operating at 250 V and drawing 4 mA is a 1 W transmitter. Even when operated at a lower supply voltage and with very loose antenna coupling, it was still very easy to cause interference. The use of a screen-grid tube as an RF amplifier ahead of the detector could provide good antenna isolation, but many (or most) regens did not use them.

However, modern semiconductor devices provide us with better performance while operating the detector at far-lower power levels. For example, the JFET detector shown in Fig 6 operates at 5 V and about 0.3 mA of detector current, which is only 1.5 mW.

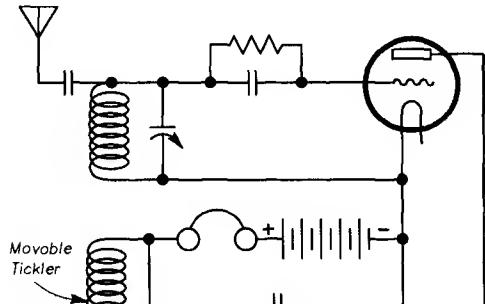
Despite this reduction in potential interference, it is still good engineering practice to use an RF stage to provide further isolation between the detector and the antenna. An RF stage prevents the antenna from absorbing power from the detector at frequencies where the antenna is resonant. It also prevents "aeronautical effects," where an antenna that swings in the wind changes the oscillation frequency of the detector. Finally, the RF stage provides gain that is often needed at the higher shortwave frequencies.

Many published articles recommend a tuned RF stage for their receivers. Although this is very sensible for a direct-conversion or superhet design, a tuned stage is both unnecessary and undesirable for a regen. The typical tuned RF stage shown in Fig 5A⁸ uses a bipolar transistor (Q1),

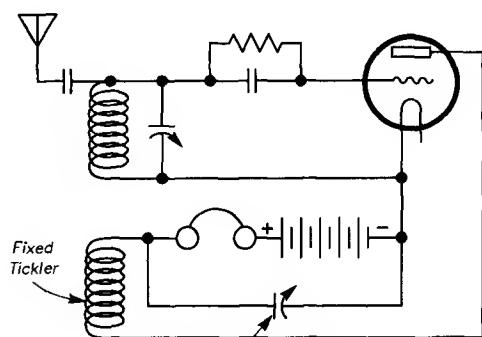
operating as a common-emitter amplifier. The input signal from the antenna cannot connect directly to the tuned input circuit because the antenna's impedance would destroy its Q, and the antenna's capacitance

would detune the circuit. This requires a second winding (or a tap) on the coil. Since Q1's input impedance is very low at RF, it also requires an impedance-matching device, usually another tap or winding on the coil.

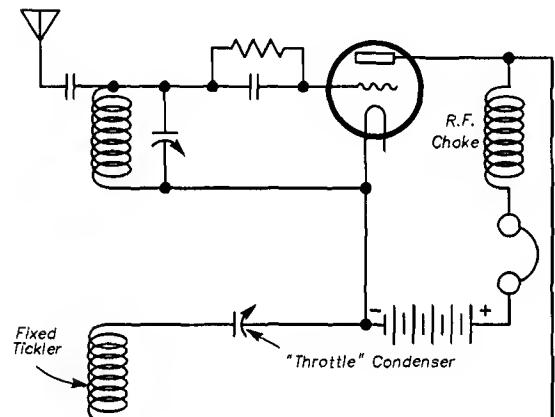
The output from Q1 couples to the tuned LC circuit of the detector. Since the input and output circuits of the RF stage are both tuned to the same frequency, with gain from Q1 in between, a "tuned-grid, tuned-plate" oscillator is



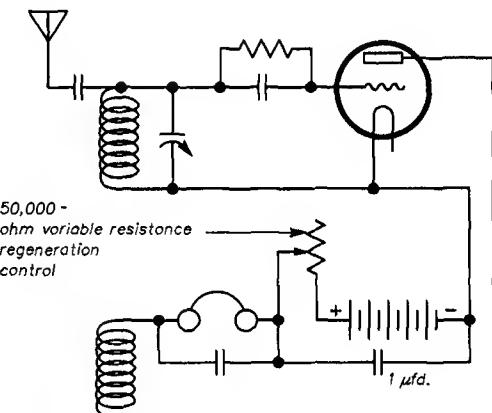
(A)



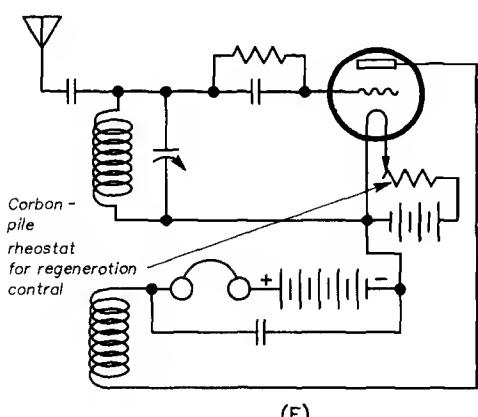
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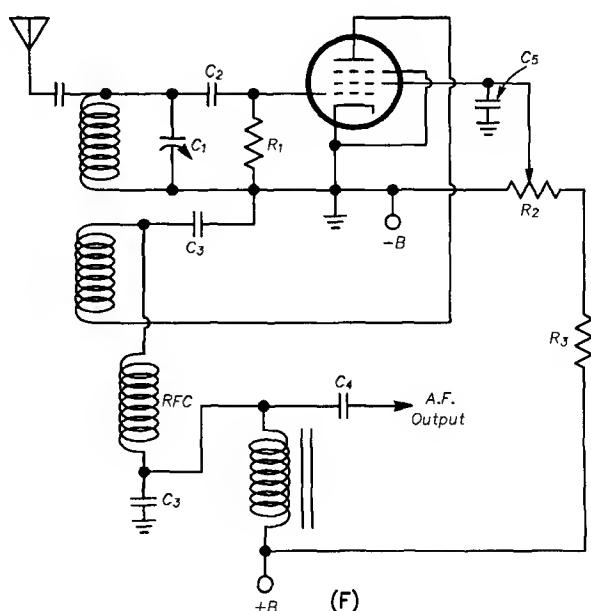
(C)



(D)



(E)



(F)

Fig 4—Regeneration control methods.

created. This usually requires that the RF stage be neutralized to prevent it from oscillating. Therefore, building a decent, nonoscillating tuned RF stage involves a fair amount of work and skill. JFET devices are also commonly used, but even with a JFET, instability problems usually require a tap on T1 (and/or T2) or the use of neutralization.

The need for neutralization can usually be avoided by operating the device as a grounded-base or grounded-gate stage, as shown in the JFET circuit of Fig 5B. Yet this still requires tapping the coil(s), and gain is lower in this configuration.

In a receiver that uses a mixer, these difficulties are often justified: It is necessary to supply enough signal to overcome the mixer noise and a high-Q tuned circuit before the mixer, to improve RF selectivity and reduce images. In a regen, however, little RF gain is needed. In fact, the detector is usually too sensitive in the oscillating mode and requires an input attenuator (more about this later).

The "Junk Box Special"

Fig 6 shows the circuit for a simple but very effective receiver that can be built using a variety of "scrounged" components. Although its parts count was kept to a minimum, this circuit still follows the guidelines previously mentioned. This design provides very good sensitivity and selectivity in the oscillating mode, as when receiving CW and SSB. AM reception is also good, but it does require frequent adjustments by the operator.

This two-band receiver covers a very wide frequency range (3 MHz to 13 MHz), is very compact and draws only 8 mA from a 6 V battery. The receiver can operate from a 5.3 to 12 V dc supply. Increase the values of R4 and R1 when operating from more than 6 V if supply current needs to be kept to a minimum.

The receiver uses a bipolar RF stage, a JFET detector, inductive coupling between the RF stage and the detector, a throttle-capacitor regeneration control, a regulated detector supply voltage and a low-cost audio amplifier IC.

Q1 operates as an untuned, grounded-base RF amplifier, providing gain and isolating the detector's oscillations from the antenna. This RF stage provides ample gain and its high output impedance does not load L2 excessively. This helps provide very high selectivity.

Too many regenerative circuits suffer from poor selectivity because of

excessive loading at their inputs. This causes the circuit to detune as the **REGEN ADJUST** control is advanced, which then allows the circuit to oscillate prematurely, at a relatively low regeneration level. With light loading, regeneration can be increased until the receiver's selectivity is a few hundred hertz. This, in fact, is an excellent operational test for any regenerative circuit.

Q1's base is tied directly to the supply: This eliminates the usual base-biasing resistors, and any variations in Beta will not effect the performance of this stage. In addition, it is now easy to set Q1's operating current. Since the base of Q1 is tied to the supply, Q1's emitter will be approximately 0.7 less positive than the supply. So, for a +6 V supply, there will be 5.3 V across R1 and 2.4 mA flowing through it ($5.3 \text{ V} / 2.2 \text{ k}\Omega = 0.0024 \text{ A}$).

By experimentation, I found that 2.5 mA is a good operating current for Q1. Too little emitter current allows detection of strong AM broadcast stations

because they overdrive the stage. (They exceed the bias voltage across R1 and cause the emitter-base junction of Q1 to detect the signal.) Excessive operating current "eats-up" the batteries. If the receiver is to be powered from a supply greater than +6 V, R1 should be increased to keep Q1's emitter current at approximately the same level. So, for +9 V operation, R1 should be about 3.5 k Ω and about 4.7 k Ω for +12 V. R4 should also be increased for +9 or +12 V operation, for the minimum-acceptable Zener current. Note that the input impedance of the RF stage is *not* R1 but much lower, as determined mainly by Q1's emitter-base junction.

C1 ac couples the antenna's signal from Q1's emitter, which prevents shorting R1 should the antenna become grounded (if you short R1, Q1 will fail). L1 inductively couples the output signal from the Q1's collector to the detector.

A Motorola type J310 or similar JFET can be used in the RF stage instead of the bipolar transistor. Simply

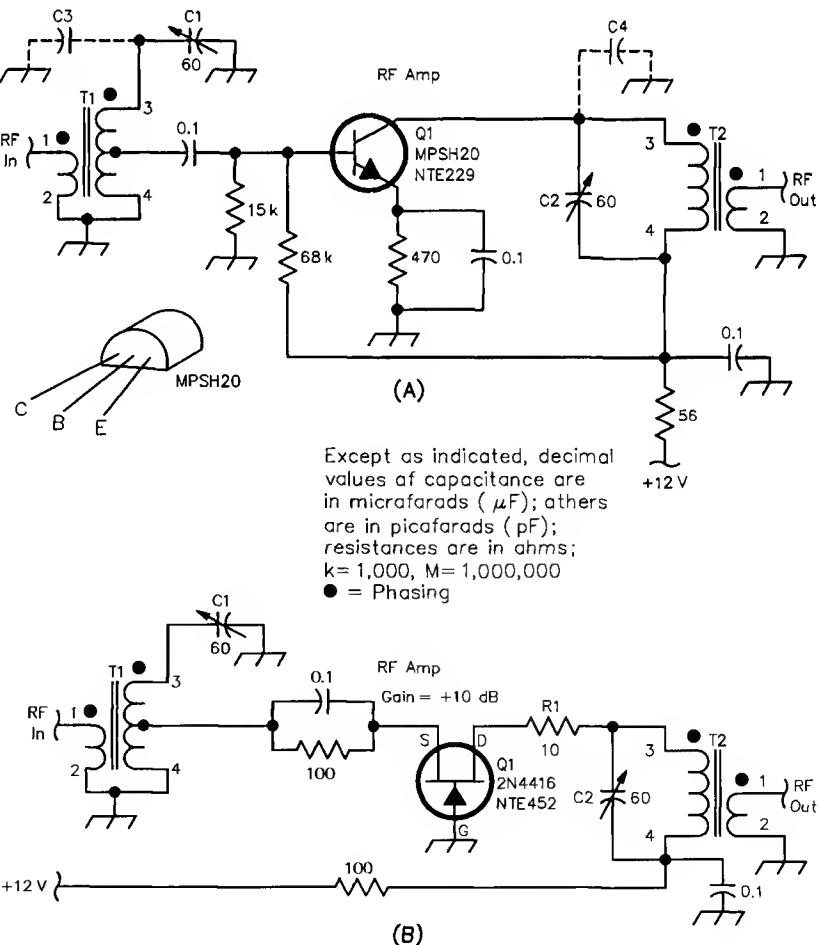


Fig 5—Typical tuned RF stages.

ground the base, connect the JFET drain to L1 and connect a $200\ \Omega$ resistor between the source and ground. The antenna connects to the JFET source through C1. The JFET RF stage has lower gain but is less likely to be affected by extremely strong local broadcast stations.

JFET Q2 operates as a regenerative detector in a Hartley oscillator circuit, the tap on L2 providing the positive feedback needed for oscillation. The optimum position of the tap depends on the gain of the active device used for the detector. If a (high-gain) bipolar transistor were used for Q2, the tap would need to be closer to the ground end of L2, to maintain the same (smooth) level of regeneration control.

C3 is a standard two-section AM-radio tuning capacitor with its trimmers removed. A single-pole miniature toggle switch, connected with very short leads, allows one or both sections to be used, providing very simple band switching. A FINE TUNE capacitor, C4, is connected in parallel with C3. A small mica capacitor, in series with C4, permits the builder to set the desired bandspread and allows the use of almost any small air-variable capacitor from the junk box.

R2 and C5 provide grid-leak bias for the detector, which (together with R3) sets the total bias level of Q2. The JFET detector is operated with a very high negative bias, keeping its gain low. For an oscillating detector, it's very important to have a low-gain device (such as a JFET) as the active element within the regenerative loop; this permits very smooth regeneration control. The old-timers of the 1920s knew this and operated their tube detectors from low supply voltages to achieve the same result. However, a high-gain bipolar transistor provides the highest sensitivity in nonoscillating operation. So, a detector using a 2N2222 or similar transistor will make a very sensitive AM shortwave receiver that needs only a 39-inch whip antenna to get hundreds of stations. This receiver will have poor CW and SSB performance, however.

The RC time constant of R2 and C5 is long enough that AF amplitude variations in the RF carrier cannot "leak off" fast enough and therefore change the dc bias level of the JFET. These bias variations cause the JFET's operating current to change along with the modulation, providing AM signal detection. The grid-leak biasing tends to maintain the detector's oscillations at constant amplitude, which improves the

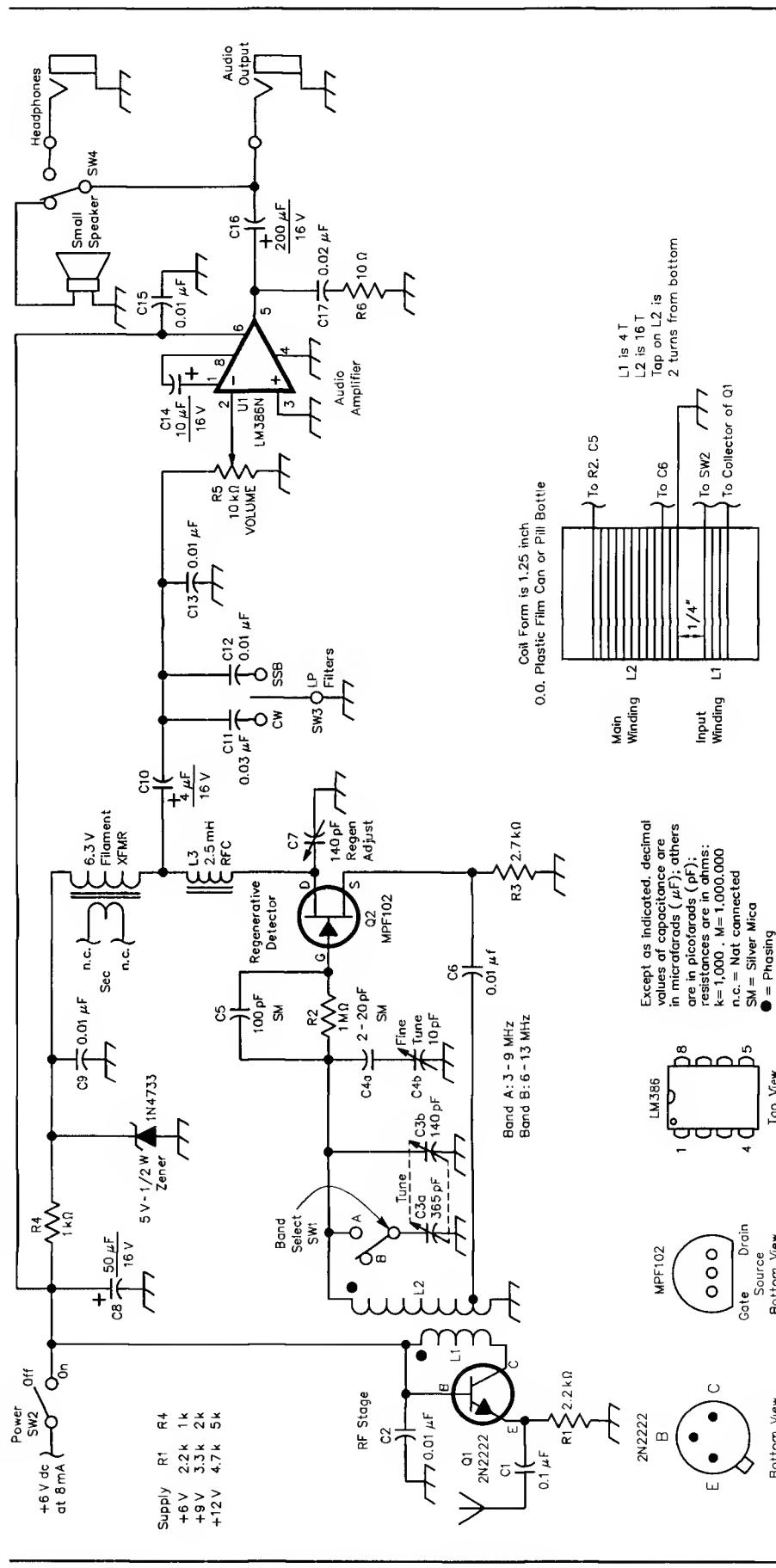


Fig 6—The Junk Box Special, a low-cost shortwave receiver.

circuit's stability for CW and SSB reception.

C7 is the throttle-capacitor **REGEN ADJUST** control. As C7's capacitance is increased, more RF energy is coupled from Q2's drain to ground (and therefore the ground end of L2); this eventually initiates an RF oscillation. RF choke L3 isolates Q2's RF feedback from the detected audio, allowing just the audio signal to pass on to L4. L4 is the primary winding of a small 6.3 V filament transformer. This inductor allows the audio signal to be extracted from the detector without introducing additional series resistance in Q2's drain circuit. This helps minimize detector frequency drift.

Note that almost any small transformer with a 120 V winding can be used. You can also substitute vacuum-tube-television vertical-output transformers or the primary windings of vacuum-tube audio-output transformers. Alternatively, omit the transformer and connect C10 in series with a 1 or 2 k Ω resistor to Q2's source. This connection provides a lower audio-output level, but it is adequate for headphone reception. The resistor method also eliminates any "howling" (audio oscillation) effects that sometimes occur when a large inductance is used to extract the audio.

A Zener diode holds the detector's supply voltage constant. This greatly reduces frequency drift for CW and SSB operation and allows the regeneration level to be set much closer to the oscillation threshold for AM reception.

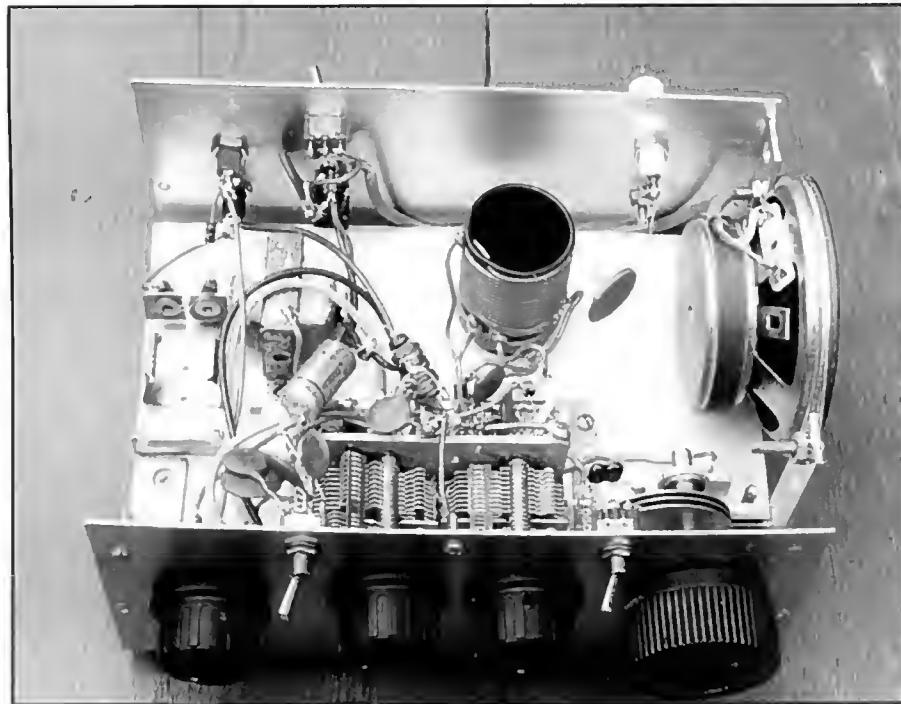
The audio signal travels via C10 to the **VOLUME** control, R5. SW2, a single-pole, double-throw (center-off) toggle, selects one of two capacitors to reduce the audio bandwidth. An LM386 audio-amplifier IC provides adequate volume to drive headphones or a small speaker. I suggest using a socket with the LM386 so you can change this chip easily. (The original device used in my prototype was *very* noisy and prone to oscillate. I suspect that many of Radio Shack's LM386s have similar flaws.) R6 and capacitor C15 help prevent the IC from self-oscillating.

This receiver was built to be very portable. The enclosure is the bottom half of a 5 $\frac{1}{8}$ ×7 $\frac{7}{8}$ ×3 $\frac{1}{2}$ -inch metal box. A piece of $\frac{3}{4}$ -inch-thick wood was cut to fit the inside bottom of the box. Wood screws hold the wood to the metal; they also secure the circuit board and other components to the wood. To mount the film-can coil form, I drilled a small hole in its bottom and attached it to the wood using a small

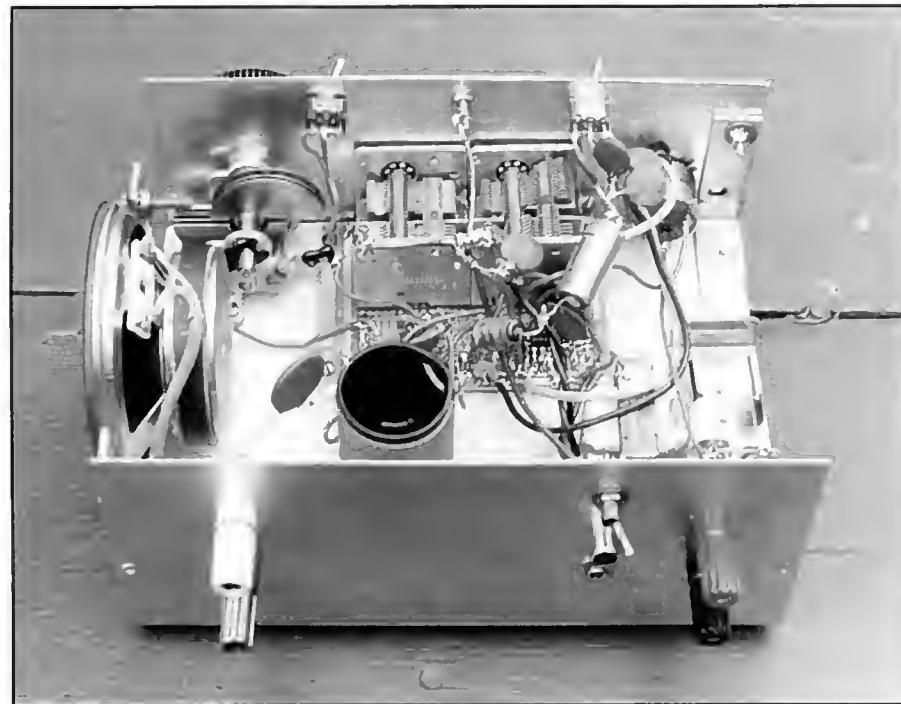
brass wood screw. The wood bottom not only makes construction much easier, but helps minimize any loading effects on the main tuning coil.

The regeneration throttle capacitor and main tuning capacitors are attached directly to the ground plane of

the circuit board; their shafts extend through holes drilled in the box side that serves as the front panel. All other controls were mounted directly to the front panel. Plastic knobs were used for all the controls; they don't increase hand-capacitance effects. Because I



(A)



(B)

Photos A and B—The upper photo shows a top-front view and the lower photo a top-rear view of the Junk Box Special regen receiver.

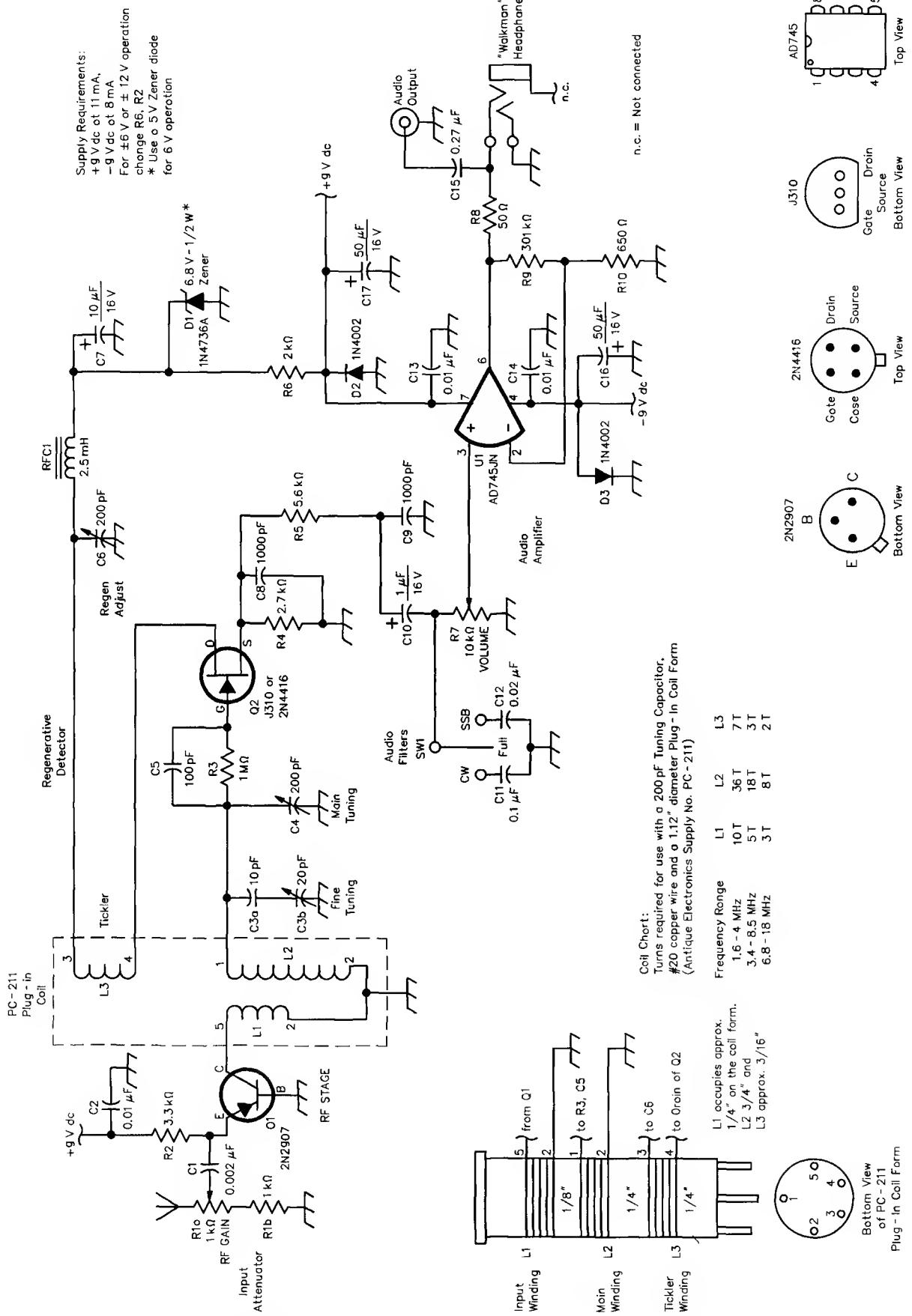


Fig 7—A high performance shortwave receiver.

was building a very compact receiver, I used small knobs for all controls except the fine-tuning capacitor, which has a larger knob. For general-purpose AM shortwave reception, I suggest using a larger front panel with large knobs or a vernier dial for the **REGEN ADJUST** and **main-TUNE** (band-set) capacitors to make these adjustments easier. For CW and SSB, the small knobs are perfectly adequate.

A High-Performance Shortwave Receiver

Fig 7 shows a highly sensitive and selective shortwave receiver that is easy (and fun) to operate. As with the previous circuit, this design uses a bipolar RF stage, a JFET detector and an IC audio stage. The overall performance of this circuit equals that of many superhet designs, yet it has very few parts and draws less than 12 mA from its two 9 V batteries.

In this circuit, the RF stage uses a PNP transistor for Q1. This allows one end of L1 to be grounded, permitting the use of a five-pin plug-in coil form for L1, L2 and L3. R1 is a simple but very effective input attenuator that serves as an **RF GAIN** control. As before, the RF stage is inductively coupled to the detector via L1. This maximizes signal transfer to the detector without loading it down. JFET Q2 operates as a tickler feedback or Armstrong regenerative detector circuit. This receiver uses a 2N4416 JFET (or J310), which provides a more sensitive detector than an MPF102.

Secondary winding L2 and capacitors C3 and C4 select the received signal while tickler winding L3 provides regenerative feedback. R3/C5 are a "grid leak" arrangement that (together with R4) sets a very high level of operating bias for the JFET, making regeneration control much smoother.

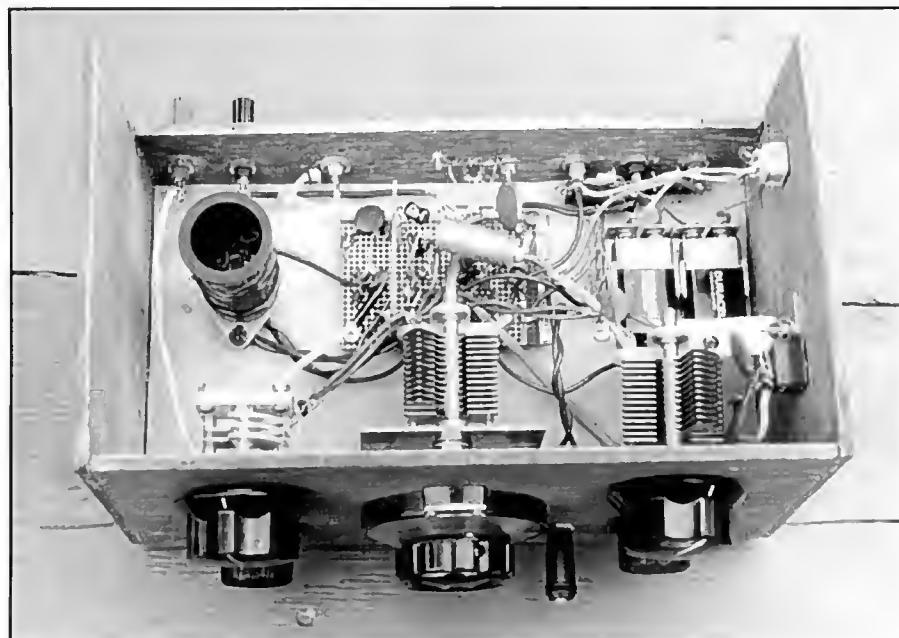
C6 is the throttle-capacitor **REGENERATION** control, while RFC1 isolates the RF signal from the power supply. Zener diode D1 regulates the drain voltage of the detector so that it is very stable in the oscillating mode. A commercial plug-in coil form (Antique Electronics Supply PC-211⁹) allows multiband operation (band switching would be difficult with three windings). To increase the frequency range of this receiver, it is only necessary to wind another coil. Operation can be extended all the way down to the long-wave frequencies and as high as the 10-meter band. When winding coils, corresponding windings should occupy about the same length (expand

or compress turns as necessary) and position (along the form) on all coils. This helps to reduce the capacitance.

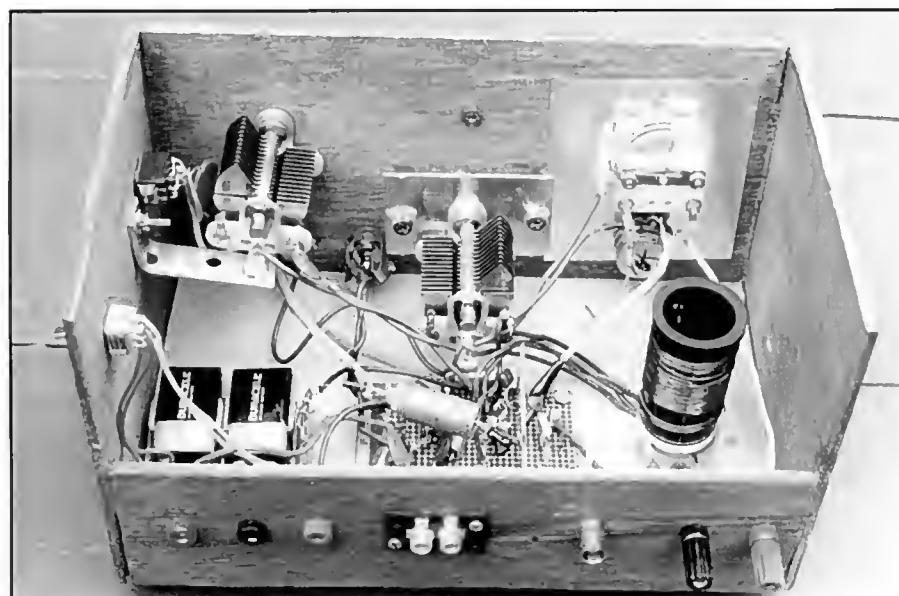
The audio output is extracted from the JFET source and travels through resistor R5 to the audio filters. R5 isolates C11 and C12 from R4 and C8 in the detector's source; otherwise, the detector may break into superregeneration. This can occur with high levels of RF feedback when a long RC time constant is used in the detector circuit. A large increase in either R3 or C5

would produce the same effect. I suspect that many RF oscillators in superhet and D-C receivers suffer from similar superregenerative (secondary oscillation) effects, which can severely degrade performance. However, very few people know about this phenomenon.

The audio-filter switch (SW1) can connect additional capacitance across R7, reducing the high-frequency audio response. A similar switch could be added to reduce the receiver's low-



(C)



(D)

Photos C and D—The upper photo shows a top-front view and the lower photo a top-rear view of the High Performance regen receiver.

frequency response, or better still, an active bandpass filter could be added for CW reception. Audio feeds from the **VOLUME** control (R7) to an Analog Devices AD745 opamp. There is considerable justification for using this opamp; it provides high gain and very low noise, high-quality audio. A good quality audio stage plus hi-fi (eg, Sony Walkman) headphones greatly improve shortwave listening pleasure. As shown, the opamp output drives the headphones series connected (common not used).

This receiver uses large knobs and a vernier dial to make it very comfortable to tune and adjust. The enclosure is made entirely of wood to minimize any loading effects. It uses a $6 \times 2\frac{1}{2}$ -inch poplar board for the base. The front panel, back and sides are made from $\frac{1}{4}$ -inch mahogany plywood. (See photos C and D.) There are two 9 V battery holders inside, plus banana jacks for an external battery or other power supply.

Fig 8 shows some optional accessories. Fig 8A shows how a small pick-up loop can be added to permit direct frequency readout using an external low-cost frequency counter. The pick-up loop is located close to the detector coil to extract some signal from the detector when it oscillates. A BNC connector and a short length of $50\ \Omega$ cable connect the loop to the counter. Note that, unlike a superhet receiver, the frequency counter will display the actual frequency being received, and it is NOT necessary to subtract (or add) the IF. [Unless you are at zero-beat, however, the oscillator will be offset from the signal by the beat note frequency.—Ed]

Fig 8B shows a dual-polarity ac power supply. Always test your receiver with batteries first, then try the ac power supply. Note that any power supply for a regen set should be separated from the receiver and connected to it via a 2 to 3 foot cable. This prevents 60 Hz ac from being coupled into the receiver from the power supply transformer or ac line cord. It is also important that the power supply be well filtered and that it use a three-prong (grounded) line cord. This connects the ac line ground to the power supply's dc common. This ensures that the ac line ground and the receiver's ground are tied together.

Also, be sure to add additional bypass capacitors to all dc power leads at the point where they enter the receiver. In some cases, RF energy from the oscillating detector finds its way into the power supply, "hum modu-

lates" the dc and is then picked up by the receiver. If simply bypassing the power supply leads proves ineffective, connect a low-dc-resistance RF choke in series with the dc supply line(s). Attention to these details will greatly reduce any background hum when the detector is oscillating.

Fig 8C shows how to add a **FINE REGENERATION** control to either receiver. If the receiver is to be used for serious AM shortwave reception, the **REGEN ADJUST** control should have a large knob, a vernier dial or a separate **FINE REGENERATION** control. This control is made exactly the same way as a fine-tuning control, using a small air variable in parallel with the main **REGEN ADJUST** control.

Fig 8D is a circuit using a potentiometer and a common rectifier diode to replace the small variable capacitor used for fine tuning.

Construction Guidelines

Use a wooden chassis: A metal chassis, shield cans etc all absorb energy from the main tuning coil and add to its losses, which directly affect the overall circuit Q and the selectivity of

the receiver. [The wooden housing, while inexpensive and easy to fabricate, will not provide any shielding for radiation from the oscillator, which may become an interference problem. If you keep the ends of the coils at least three coil diameters, and the sides of the coils one diameter away from a metal chassis, the effect of the chassis on Q will be very small.—Ed] The old timers of the 1920s knew this and used wooden cutting boards (breadboards) as receiver chassis. The optimum setup for a homebrew regen is a wooden base, sides and back with a grounded, metal front panel. A wooden front panel can also be used if you take precautions to reduce hand-capacitance effects. The metal bodies of the controls should be grounded and a small, grounded sheet-metal plate should be placed between the **FINE TUNING** control and the back of the front panel. As shown, fine tuning can be incorporated into these receivers by adding a small variable capacitor in parallel with the main tuning capacitor.

It's also best to build your receiver large so there is room to use large knobs for tuning and regeneration

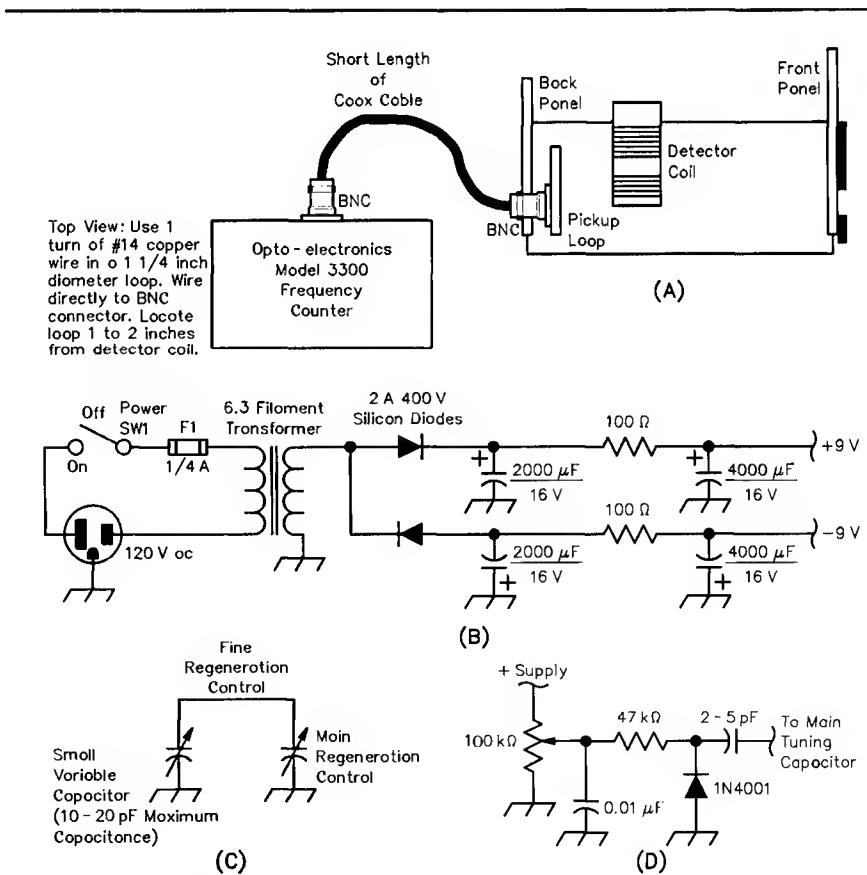


Fig 8—Optional receiver accessories.

control. For general-coverage receivers, use a large knob or a vernier dial on the main tuning capacitor; for ham receivers, put the vernier on the **FINE TUNING** control for maximum bandspread on the amateur bands.

Build the electronics on a small fiberglass board and then attach it to the wooden base. Many common items can be used for coil forms, including plastic film cans, pill bottles, PVC pipe etc. You can test the coil form by heating it (along with a cup of water) in a microwave oven for a minute or so. If the form heats up, its dielectric absorption is too high.

I normally use #20 stranded insulated hook-up wire (Radio Shack RS#278-1219) for the coils. Insulated wire spaces the turns very evenly and holds them together very tightly. However, for small coil forms with many turns, enameled solid copper wire can be used.

When winding coils, drill two small holes in the coil form at the beginning of each winding. Feed the wire into the form through the first hole and out through the second. Before you start the winding, simply tie a knot at the point in the wire where it enters the form—this will keep the wire from loosening later. Then wind the coil tightly onto the form. When the winding is finished, drill two more holes at the end of the winding and feed the wire through. When the coil is finished (and working correctly) use Q Dope to cement the windings firmly to the form.

With plug-in coils, run the wires from each winding inside the coil form and then solder them to one of the pins, being sure that all coils are wired exactly the same way. The coil then plugs into a tube socket on the receiver's baseboard. Be sure to locate the coil at least 1 inch from any metal object.

Try to arrange the receiver's layout to keep all leads as short as possible. Physically separate the audio wiring from the RF wiring. The **VOLUME** control should be connected using shielded wire, with a separate wire between the control ground terminal and chassis ground (to avoid ground loops through the shield). Opamps and other ICs should have their power-supply bypass capacitors located right at the chip, using short leads to ground. Universal breadboards (such as the Radio Shack RS#276-168) simplify construction and allow you to ground the unused sections to serve as a ground plane. Standard low-cost fiberglass board can also be used if a copper-clad board is located below it on spacers with all

grounds connecting to the copper board.

Testing

Always build receiver circuits backwards. Start with the audio stage, then the detector and finally, the RF stage. Be sure each stage is functioning correctly before building the next. Wire the audio stage as far back as the volume control, then connect the batteries and headphone and do a quick test. You can just place your finger on the top of the control and listen for a buzz in the headphones. Once the audio stage is working, wire and test the detector, but without the RF stage. Wire the detector as far back as the main tuning coil. Connect a short piece of wire (a foot or two) to the primary winding, L1, right at the point where the collector of Q1 will be connected. Slowly turn-up the regeneration control until the detector oscillates, producing a "live sound" (a large increase in background noise).

If the detector refuses to oscillate, carefully check the wiring. Once you are sure the wiring is okay, check the voltage across the Zener diode (5 V Fig 1, 6.8 V Fig 2) at the drain of Q2 (same voltage as the Zener), and at the source of Q2 (about +1 V to +1.5 V). If the voltages are correct, try moving the tap on L2 more above ground (see Fig 6) or try swapping the wires to the tickler winding (see Fig 7). Once the detector is oscillating, replace the short wire with an outside antenna in series with a 5 to 20 pF capacitor. Tune-in a strong station, adjusting the regeneration level and **VOLUME** for best reception. Test the RF stage by connecting the antenna to the receiver's input and listening to the same station. Reception should be at least as good as without the RF stage. (In the upper HF region, it should be much better.)

Tuning Tips

For AM reception, increase the regeneration level until the detector just barely oscillates. Then use the main tuning (bandset) capacitor to get close to the desired signal. Reduce the regeneration level to just below oscillation and use the fine-tuning (bandspread) capacitor to tune in the station. It's often a good idea to use two hands: One for tuning and the other for **REGENERATION** control. If the station is very weak, set the regeneration level slightly above oscillation and tune to the center of the carrier. This provides very high sensitivity, typically better than 0.3 μ V. This is a nice feature of the throttle-capacitor regeneration

control method; a simple resistive control won't let you do this.

For CW reception, set the regeneration level just into oscillation. This gives you the greatest sensitivity and selectivity. Tune the receiver to either side of the carrier for a beat note. The beat note should be very stable; if it varies at all, increase regeneration slightly. This operates the detector at a higher RF level, increasing the stabilizing effect of the grid leak bias.

SSB reception is similar to CW except it is usually beneficial to keep the regeneration level fairly high at all times, to avoid blocking and eliminate any frequency drift. Blocking occurs when the detector locks onto the center of the nearest strong carrier; reducing the input signal level or increasing regeneration prevents this. The high-performance receiver includes an input attenuator for this purpose. When using the Junk Box Special simply increase regeneration to a very high level. Strong SSB signals may need full regeneration to unblock.

Future Experimentation

I encourage all receiver homebrewers to at least consider a regenerative circuit when planning future projects. The regenerative circuit is not just a historical curiosity; it's one of several fundamental circuit technologies to consider when beginning a new design.

I think it's also important to regularly question "popular wisdom" and try out different circuit approaches. As an example, many authors state that superregenerative circuits are only good for detecting wideband signals. I have already built several superegenerative VHF receivers that effectively demodulate narrow-bandwidth FM signals.¹⁰ In this case, simply varying the shape of the quench waveform (from the usual sawtooth to a sine wave) produced the desired result.

The present availability of excellent, low-cost semiconductors and other modern components allows today's homebrewer to try many ideas that previously might have been impractical. Future developments could include regenerative/direct-conversion hybrids using a regenerative mixer stage (or a regen with a tracking BFO). Some type of regenerative AGC circuit could simplify regenerative-receiver AM operation. It would also be interesting to add a simple squelch circuit to the basic superregenerative circuit, in order to remove its characteristic nonsignal background noise.

Notes

¹Edwin Howard Armstrong, "Some Recent Developments In the Audion Receiver," *Proceedings of the Institute of Radio Engineers (IRE)*, Vol 3, No. 4, September 1915, pp 215-247. This article introduces the regenerative circuit.

²Edwin Howard Armstrong, "Some Recent Developments of Regenerative Circuits" *Proceedings of the Institute of Radio Engineers (IRE)* Vol 10, No. 4, August 1922, pp 244-260. This article introduces the superregenerative circuit.

³Charles Kitchin, "Super Regeneration: the Lost Technology," *Communications Quarterly*, Fall 1994, pp 27-40.

⁴Charles Kitchin, "Regenerative Receivers Past and Present," *Communications Quarterly*, Fall 1995, pp 7-26.

⁵This problem has recently been eliminated by use of an optocoupler for isolation. See Dan Wissell, N1BYT's, "The OCR Receiver," *QST*, June 1998, pp 35-38.

⁶The *Radio Amateur's Handbook*, 8th edition (Newington: ARRL, 1931) p 60. ARRL publications are available from your local ARRL dealer or directly from the ARRL. Mail orders to Pub Sales Dept, ARRL, 225 Main St, Newington, CT 06111-1494. You can call us toll-free at tel 888-277-5289; fax your order to 860-594-0303; or send e-mail to pubsales@arrl.org. Check out the full ARRL publications line on the World Wide Web at <http://www.arrl.org/catalog>.

⁷The *Radio Amateur's Handbook*, 19th edition (Newington: ARRL, 1942) pp 115.

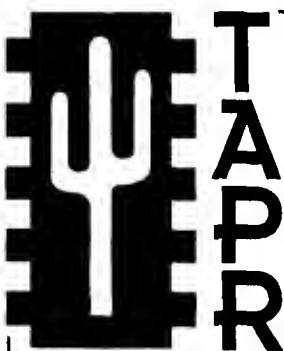
⁸Doug DeMaw, W1FB, "Doug's Desk" *CQ*, Dec 1997, p 53.

⁹Antique Electronic Supply, 6221 South Maple Ave, PO Box 27468, Tempe, AZ 85285-7468; tel 602-820-5411, fax 602-820-4643; URL <http://www.tubesandmore.com>.

¹⁰Charles Kitchin, "An Ultra Simple Receiver for 6 Meters," *QST*, Dec 1997, pp 39-41.

Charles (Chuck) Kitchin, N1TEV, is a hardware applications engineer at Analog Devices Semiconductor Division in Wilmington, Massachusetts. His main responsibilities include customer applications support and writing technical publications such as application notes and data sheets. He has published over 50 technical articles and two applications booklets.

Chuck graduated with an ASET from Wentworth Institute in Boston. Afterwards, he continued studying electrical engineering at the University of Lowell's evening division. Chuck has been an avid radio builder and shortwave listener since childhood, and a licensed radio amateur (*Technician Plus*) for three years. His other hobbies include astronomy, brewing beer and oil painting. □□



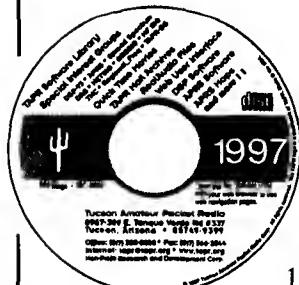
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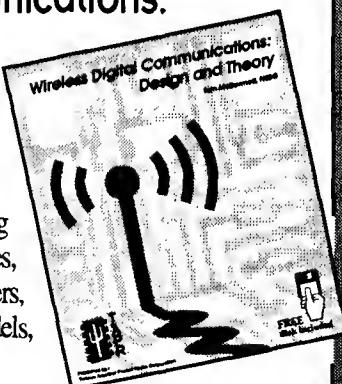
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